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Practical Risk Analysis for Safety Management

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FOREWORD

In the study of explosives and their applications, safety is of paramount importance. This report describes a practical risk analysis system which was developed as an outgrowth of safety considerations for a continuing program of explosive blast effects.

The study described in this report was performed during fiscal year 1976 and supported by Navy Director of Laboratory Programs Task Assignment R000 01 01.

This report has been prepared primarily for timely presentation of information. Although care has been taken in the preparation of the technical material presented, conclusions drawn are not necessarily final and may be subject to revision.

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SUMMARY

Proper safety measures can make positive contributions toward increased production and reduced operating expense. Basic maxims for such programs can be summarized as (1) risk can never be completely eliminated, (2) care and effort can reduce risk, and (3) efforts to reduce risk should achieve maximum possible benefits.

It is taken here that risk increases with the likelihood of some hazardous event, with exposure to that hazard, and with possible consequences of the event. Numerical scales for these three factors are developed; an overall risk score is then given as the product of these three factors. This risk score can be correlated with experience and ranges from a situation where an operation should be discontinued through one where attention is needed, and down to one where the risk is considered acceptable by our current social standards.

Justification for a proposed risk reduction measure is taken as increasing with increasing risk score and with effectiveness of the proposed measure, and decreasing with increased costs. A justification factor so assigned varies from that for a highly worthwhile effort down to efforts of doubtful merit. Such assigned justification factors make it possible to establish realistic priorities within the safety program.

The mathematical operations involved here are relatively simple and are performed either algebraically or graphically on nomographs. These nomographs permit direct entry through descriptive terms; they give both numerical and descriptive answers. Such answers are meaningful not only to safety personnel but also to management and operating personnel. The graphical method also provides written documentation for the analysis.

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INTRODUCTION

A successful accident prevention program, aside from its humanitarian aspects, makes positive contributions to production rates and to reduced operating expense. Much progress in such a program has been made in the last few decades. However, there is still room for improvement, which is well indicated by the observation that currently in the United States each year there are about 2,500,000 work-related disabling accidents with about 50,000,000 man-days of lost time and some 14,000 fatalities, and that the cost of such accidents is about $14,000,000,000.[1]

A safety management program designed to reduce the toll from industrial accidents requires considerable thought, effort, and compromise, or it can prove to be both wasteful and ineffective. A mathematical approach that avoids these defects is presented here.

SAFETY CONSIDERATIONS

A safety program should be based on documented factual information and on informed judgement, and not on subjectivity or intuition. Likewise, safety recommendations should be quantitative in nature so that alternative proposals can readily be evaluated, urgencies assessed, and safety priorities established. Furthermore, to be effective all safety terms should be expressed simply so that they are understandable by both operating and management personnel.[2,3]

Safety programs, desirable as they are, present difficulties. One concerns the level of effort that should be devoted to a safety program. A low level of effort may be inadequate and not achieve its purpose. Alternatively, the effort can be so intense that an entire operation is hampered to such an extent that no useful work can be accomplished.

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[1] *Accident Facts*, published annually by the National Safety Council, 425 N. Michigan Ave., Chicago, Ill.

[2] Rollin H. Simonds and John V. Grimaldi. *Safety Management: Accident Cost and Control*. Homewood, Ill., Richard D. Irwin, Inc., 1963.

[3] H. W. Henrich. *Industrial Accident Prevention: A Scientific Approach*. New York, McGraw-Hill, 1959.

From such considerations it follows that there is a best safety program for each situation. The following material describes one method for achieving this optimum.

Hazard

The word "hazard" implies a definite danger, particularly from some unanticipated and possibly fortuitous event that is beyond one's immediate control. Examples include such hazards as a passenger being killed in an automobile accident—there are some 50,000 such fatalities in the United States each year; being struck by lightning; and choking to death on a bite of steak. It is apparent that our ordinary daily activities expose us to many such hazards. Table 1 lists some of these using data from standard sources such as the National Safety Council[1] and World Almanacs.

TABLE 1. Some Well-Known Hazards Encountered in Daily Activities. United States, 1975.

Hazard	Risk
Riding in an automobile	56,000 fatalities
Working	14,200 fatalities; 2,500,000 disabling accidents
Flying	1,500 fatalities
Swimming	7,300 drownings
Staying home	6,800 fatalities from 2,700,000 fires
Going to church	10 to 15 fatalities from 4,300 fires
Eating a steak	3,000 choking to death
Playing golf	150 killed by lightning
Nuclear power plant incidents	None

Risk

The word "risk," or the equivalent phrase "amount of risk," indicates the chance that some particular hazard may actually cause injury or damage. Risk can be described in statistical-like terms. Thus the risk involved in riding in an automobile can be expressed by the observation that in the United States there are some 45 driver-plus-passenger fatalities per 1,000,000,000 vehicle miles. The risk of being killed by lightning while playing golf can be described as about one fatality per 10,000,000 golf games, and the risk of choking to death on a steak as about one fatality per 500,000,000 steaks, and so on. Table 2 shows some typical risks.

TABLE 2. Amounts of Risk Typically Considered Acceptable. United States, 1975.

Hazard	Risk
Riding in an automobile........	45 fatalities per 10^9 vehicle-miles; 1 fatality per 1,000 rider-years
Flying, scheduled flights......	1.3 fatalities per 10^9 passenger miles
Flying, all flights............	20 fatalities per 10^9 rider-miles
Working........................	1 fatality per 4,500 worker-years
Riding a bicycle...............	1 hospitalization per 10^4 rider-miles
Hurricanes.....................	1 fatality per 2,500,000 person-years
All accidents..................	1 fatality per 1600 person-years
Nuclear reactor operation......	1 "incident" per 3×10^8 reactor-years

The Acceptable Risk

Since we cannot completely avoid all the hazards in our ordinary lives, all risk from such hazards can never be completely eliminated. However, one often takes steps to reduce the risk associated with some particular hazard. Thus when we drive carefully with seat belts fastened, we reduce the risk of becoming an automobile accident fatality. Similarly we avoid open stretches of a golf course when a thunderstorm is impending, and we eat our steaks in well-chewed small bites.

The above lugubrious thoughts serve to introduce the concept of the acceptable risk, as suggested by Dr. Billings Brown of the Safety Division of the American Ordnance Association.* An acceptable risk can be defined as that real risk imposed by some hazard, but one that under the circumstances would not deter a knowledgeable and prudent person. Thus, the risks of riding in an automobile, playing golf, or eating a steak, are regarded by some people as acceptable risks. In any event such risks often seem preferred over *never* driving or riding in an automobile, *never* going out-of-doors, or *never* eating solid food.

* Private communication, 1968.

Convenience plays a part in setting an acceptable level of risk. Thus the risk of being killed in an automobile accident is about one per 1,000 rider-years and obviously is considered acceptable to many of us. This acceptance must be based in part on a rationalization such as, "I will never live for one thousand years, hence I will never be one of these fatalities."

Other circumstances play a part in determining what risk is acceptable. This can be illustrated by comparing data for riding in airplanes with those for riding in automobiles. The risk of traveling by airplane is far less than traveling by automobile, but there are some people who avoid airplane travel even though they ride in automobiles. And what is considered an acceptable level for risk in industrial work is well below that considered acceptable in either the airplane or automobile mode of travel. This low level of acceptable risk for industrial work merits approval; however, to achieve and maintain this level requires effort, along with optimum use of the available resources of time, material, and money.

The Safety Maxims

The basic thoughts behind the observations above can be formalized in safety maxims, as follows:

1. All the many hazards in life cannot be completely avoided, and all risks from such hazards can never be completely eliminated.

2. Careful thought and effort can often reduce the risks in ordinary life down to acceptable levels.

3. Our limited resources of time and effort should be utilized for maximum benefits of risk reduction rather than being dissipated in hopeless efforts to completely eliminate certain selected risks.

These safety maxims are well accepted in the technical community even though in some situations, legal ones for example, they may not be considered relevant. These safety maxims have led to a system as developed here for quantitative characterization of risks and for evaluation of proposed risk-reduction procedures. This system uses numerical values for comparison purposes. It also provides descriptive terms that are meaningful, not only to safety personnel but also to those in management and in operations. Such a system was first suggested in a report by William T. Fine, and many of the evaluations here are based on that report.[4]

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[4] Naval Ordnance Laboratory. *Mathematical Evaluations for Controlling Hazards,* by William T. Fine. White Oak, Md., NOL, 1971. (NOLTR 71-31, publication UNCLASSIFIED.)

RISK CALCULATION

The risk imposed by some particular hazard can be taken as increasing (1) with the likelihood that the hazardous event will actually occur, (2) with exposure to that event, and (3) with possible consequences of that event. For risk calculations, numerical values are assigned to each of these three factors. Then an overall risk score is computed as the product of these three separate factors. The numerical values, although arbitrarily chosen, are self-consistent and together they provide a realistic but relative score for the overall risk.

Likelihood of Hazardous Event

The likelihood of occurrence of a hazardous event is related to the mathematical probability that it might actually occur. For purposes here, however, likelihood is expressed in alternative terms of expectations. Likelihoods that may be encountered in practical safety situations range from the completely unexpected and unanticipated, but remotely possible, up to an event that might well be expected at some future time.

An example of the first of these, an unexpected but remotely possible event, is failure of a proof-tested container of compressed gases. For mathematical purposes the likelihood factor for such an event is arbitrarily assigned the value of unity. An example of the second type of hazardous event, one which might well be expected at some future time, is combustible material catching on fire in a drying oven, particularly if this has happened in the recent past. The likelihood factor for such an event is assigned the value of 10.

These two likelihoods provide reference points on a scale of likelihoods for ordinary hazardous events. Situations between these two reference likelihoods are then readily assigned intermediate values. For example, a "could happen" type of event is assigned a likelihood value such as six, and an event that would be unusual, but still quite possible, is assigned a value of three.

Safety considerations must provide not only for all such possible situations, but also for ones that approach the impossible. The absolutely impossible event would be assigned a likelihood value of zero. However, no event that can be described can ever be considered as being absolutely impossible; that is, have a mathematical probability of zero. Nevertheless, its probability can approach zero so closely that the event is virtually impossible. A likelihood value of one-tenth is assigned to this virtually impossible situation, which thus becomes another reference point for the likelihood scale.

This two-decade scale for likelihood factors ranges from the value of one-tenth for the virtually impossible event, through the value of unity for an unexpected but remotely possible event, up to the value of 10 for an expected event. These reference points plus interpolated values are as follows:

Likelihood	Value
*Might well be expected	10
Quite possible	6
Unusual but possible	3
*Only remotely possible	1
Conceivable but very unlikely	0.5
Practically impossible	0.2
*Virtually impossible	0.1

The Exposure Factor

The greater the exposure to a potentially dangerous situation the greater is the associated risk. To provide for this, the value of unity is assigned to the situation of a rather rare exposure, perhaps only a very few times per year. Then the value of 10 is assigned for continuous exposure. Interpolation between these two reference points provides for intermediate values, thus the value of three is assigned for a weekly exposure. Extrapolation is needed to provide for situations of a very rare exposure, and indeed the value of zero would be assigned for no exposure at all.

Likelihood	Value
*Continuous	10
Frequent (daily)	6
Occasional (weekly)	3
Unusual (monthly)	2
*Rare (a few per year)	1
Very rare (yearly)	0.5

Factors for Possible Consequences

Damage from a hazardous event can range all the way from minor damage that is barely noticeable up to the catastrophic. This very wide range is taken as extending over two decades in numerical values. Thus the reference value of unity is assigned for the noticeable situation and the value of 100 for the catastrophic.

---

*Reference point.

The noticeable situation is taken as one that involves a material damage of perhaps $100, or an incident that would be classified as a minor first aid accident. The catastrophic situation is taken as one where there are many fatalities, or where there is a material loss of millions of dollars. Intermediate factors are readily assigned; for example, a disaster with a few fatalities or with material damage greater than about $1,000,000 would carry the value of 40. Also included are the very serious, the serious, and the important situations. Consequence factors and values for these situations are included below:

Possible consequence	Value
*Catastrophe (many fatalities, or >$\$10^7$ damage)....	100
Disaster (few fatalities, or >$\$10^6$ damage)........	40
Very serious (fatality, or >$\$10^5$ damage)..........	15
Serious (serious injury, or >$\$10^4$ damage).........	7
Important (disability, or >$\$10^3$ damage)...........	3
*Noticeable (minor first aid accident, or >$100 damage)..................................	1

It can be noted that the relation between possible material damage and the consequence factor can be represented by the empirical formula

$$\text{factor} = (\text{damage}/100)^{0.4}$$

Consequence factors have two rather different aspects. One is personnel injury or fatality, or both. The other is material damage. In spite of possible objections, practicalities of the situation dictate a common scale for these two quite different items (such as for liability insurance). Such a common scale has an advantage in that it can provide for situations where both personal injury and material damage might occur; here the consequence factor is a weighted sum of its two diverse aspects.

Risk Score

The risk score for some potentially hazardous situation is given numerically as the product of three factors: one numerical value each for likelihood, for exposure, and for possible consequences.

Numerical risk scores, as so computed, can readily be associated with the risks observed for actual situations. Thus experience indicates that a risk score as low as 20 represents a situation of low risk, one considered acceptable by our current standards for industrial work.

---

*Reference point.

Such a risk is far less than the risks we ordinarily accept in everyday situations; for example, when we drive to work, when we mow the lawn with a power mower, or when we ride a bicycle for exercise.

Experience also indicates that a situation with a risk score in the order of 70 to 200 is one with substantial risk where, according to our current social standards, correction is needed (the social standards of years ago were not so demanding). Then there can be higher risk situations; a risk score of 200 to 400 indicates that correction is urgently needed. A very high risk score of more than 400 indicates a situation so risky that one should consider ceasing operation until at least interim measures to correct the deficiency can be implemented, or perhaps permanent shutdown becomes necessary if the operation cannot be made safe. These risk score classifications are based on experience and are subject to adjustment when experience indicates otherwise. However the classifications are very conservative and therefore provide strong statements for the risks involved.

Risk score	Risk situation
>400	Very high risk; consider discontinuing operation
200 to 400	High risk; immediate correction required
70 to 200	Substantial risk; correction needed
20 to 70	Possible risk; attention indicated
>20	Risk; perhaps acceptable

Graphical Calculation of Risk Score

Risk scores, defined above as products of three factors, can with some convenience be calculated graphically as shown in Figure 1. The likelihoods are listed on the first or left line of this nomograph. The scale is logarithmic in nature and is graduated so that distances along this line are proportional to the logarithms of the likelihood factors. However, only descriptive terms appear, and the actual numbers have been omitted. The value of zero corresponding to a hypothetical "absolutely impossible" situation cannot be shown along this line as the logarithm of zero is minus infinity. Exposure factors are listed on the second line in the nomograph. Factors for possible consequences appear along the fourth line.

To calculate a risk score using this nomograph, locations corresponding to each factor involved are first established. Then a line is drawn from the point for the likelihood factor through that for the exposure factor and extended to the tie line at the center. (Location along this tie line corresponds to the product of these two factors, but the numbers have been omitted.) A second line is drawn from this point on the tie line through that for the consequence factor and extended to the scale for the risk score. A numerical value for this risk score and its descriptive equivalent are then obtained directly.

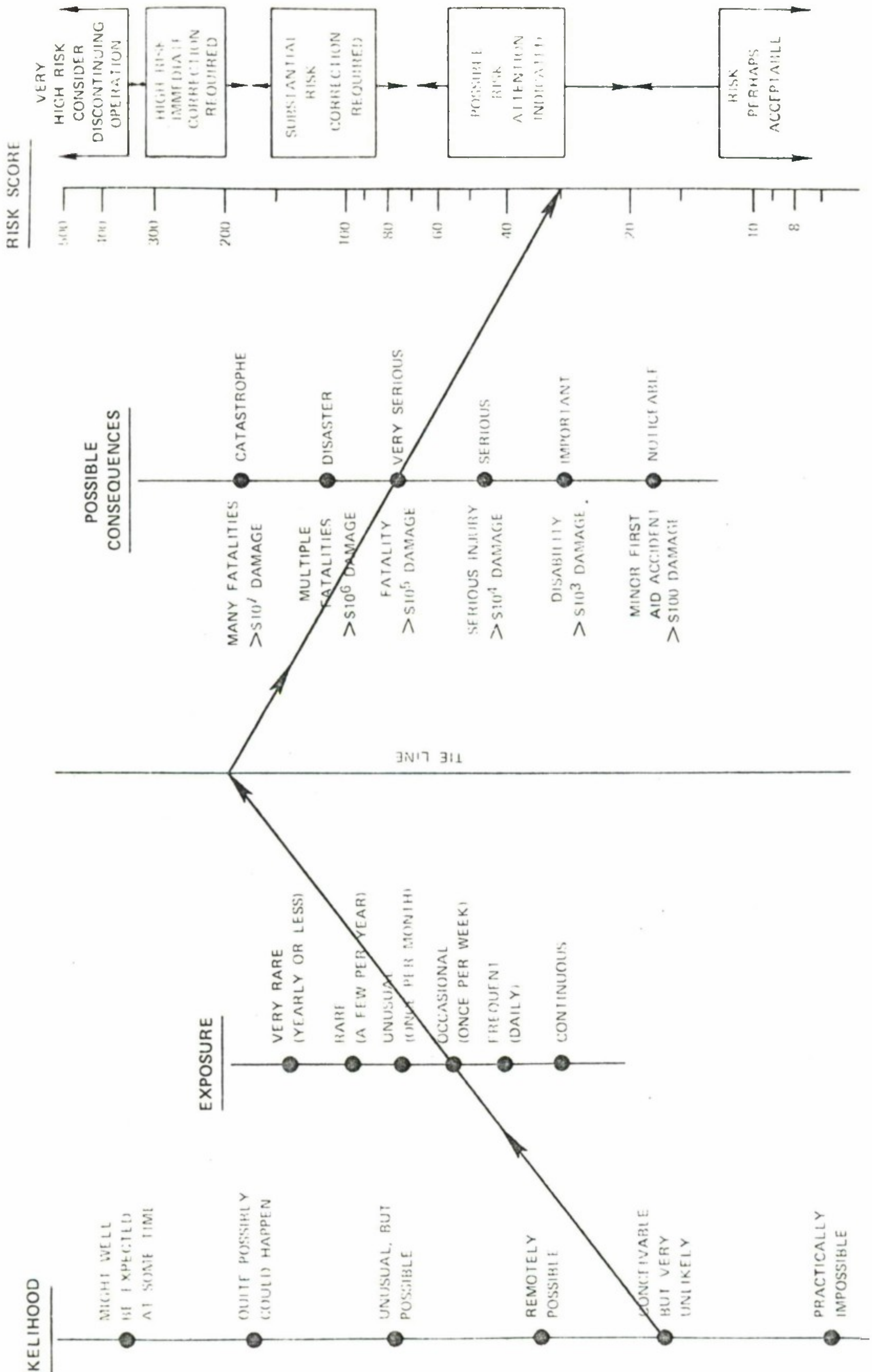

FIGURE 1. Risk Analysis.

Evaluation of a Proposed Risk-Reduction Action

The larger the risk score for a situation, the more effective a proposed corrective action, and the less that action costs, the greater is the justification. A quantitative index for this justification can be derived from numerical values assigned to each of its three component factors. These are considered separately.

Effectiveness Value

The effectiveness value assigned to a proposed risk-reduction action is taken as unity for complete elimination of risk, and zero for an action with no effect. Intermediate values are assigned accordingly; for example, a measure that would reduce risk by about 60% would be assigned an effectiveness value of 0.6.

COST CONSIDERATIONS

Cost and justification bear an inverse relation. Thus a cost factor is best expressed as a divisor whose numerical value increases with cost so that increased cost gives lesser justification.

Experience indicates that the divisor for cost is approximately proportional to the cube root of the total dollar amount included. These dollar amounts include actual out-of-pocket cost plus capitalized costs for any increase in operating or overhead expenses. On this basis the reference value of unity is assigned to the divisor representing a total cost of $100, and the value of 10 for costs of 1,000 times greater, or $100,000. The mathematical relation can be expressed in the form of an equation:

$$\text{divisor} = \sqrt[3]{\frac{\text{total cost}}{100}}$$

Cost Effectiveness

A justification factor for a proposed risk-reduction action can be obtained mathematically by multiplying the risk score for a given situation by the effectiveness factor for the proposed action and then dividing by its cost divisor. This justification factor can be taken as the cost effectiveness for the proposed action. Numerical values for this cost effectiveness have been correlated with experience. Thus, a justification value of less than about 10 indicates that a proposal is of doubtful merit. The small risk reduction does not justify the indicated expenditure of time, effort, and money, and such endeavors could well be more effective in other situations. Values between 10 and 20 indicate that action is justified. Experience suggests that a justification value greater than about 20 indicates a highly worthwhile risk-reduction action.

These values for the justification factor provide reference points for an entire scale of justification factors. This scale permits ready comparison of the merits of various proposals for reduction of identified risk. The scale is also a great aid in establishing priorities within a broad risk-reduction program.

Graphical Calculation for Cost Effectiveness

The justification factor provides an index for cost effectiveness, and like the risk score can be calculated graphically as shown in Figure 2. Entry to this nomograph is by three factors: one numerical value each for risk score as calculated previously, for degree of risk reduction that the proposed measure provides, and for its cost divisor. Lines through these points give both a numerical value and a descriptive term for the justification factor.

The graphical methods have several advantages over the algebraic. (1) When using the nomographs there is no need to refer to separate tables for values because entry can be made directly through the descriptive items of the chart. (2) The arithmetic calculation is simpler when done graphically and, although it is of limited precision, this is quite satisfactory for purposes here. (3) The graphical solution automatically provides documentation for both the risk analysis and justification calculation.

ANALYSIS OF A HAZARDOUS SITUATION

Risk Score Calculation

An access road in a processing plant carries occasional traffic passing a large tank containing propane. There is a possibility that a loaded truck on this access road might accidentally swerve from the road at a point near the tank and crash into it. If so, the tank might fail and spill its highly flammable contents. Then if these contents caught on fire, the damage could be substantial. Loss of the tank and its contents and damage inflicted on neighboring parts of the plant could cost as much as $250,000. What is the risk score for this situation?

Algebraic Solution.

1. The chain of incidents described is conceivable but quite unlikely. The likelihood factor is assigned a value of................0.5
2. Only occasional exposure (weekly) is involved. This factor is assigned a value of... 3

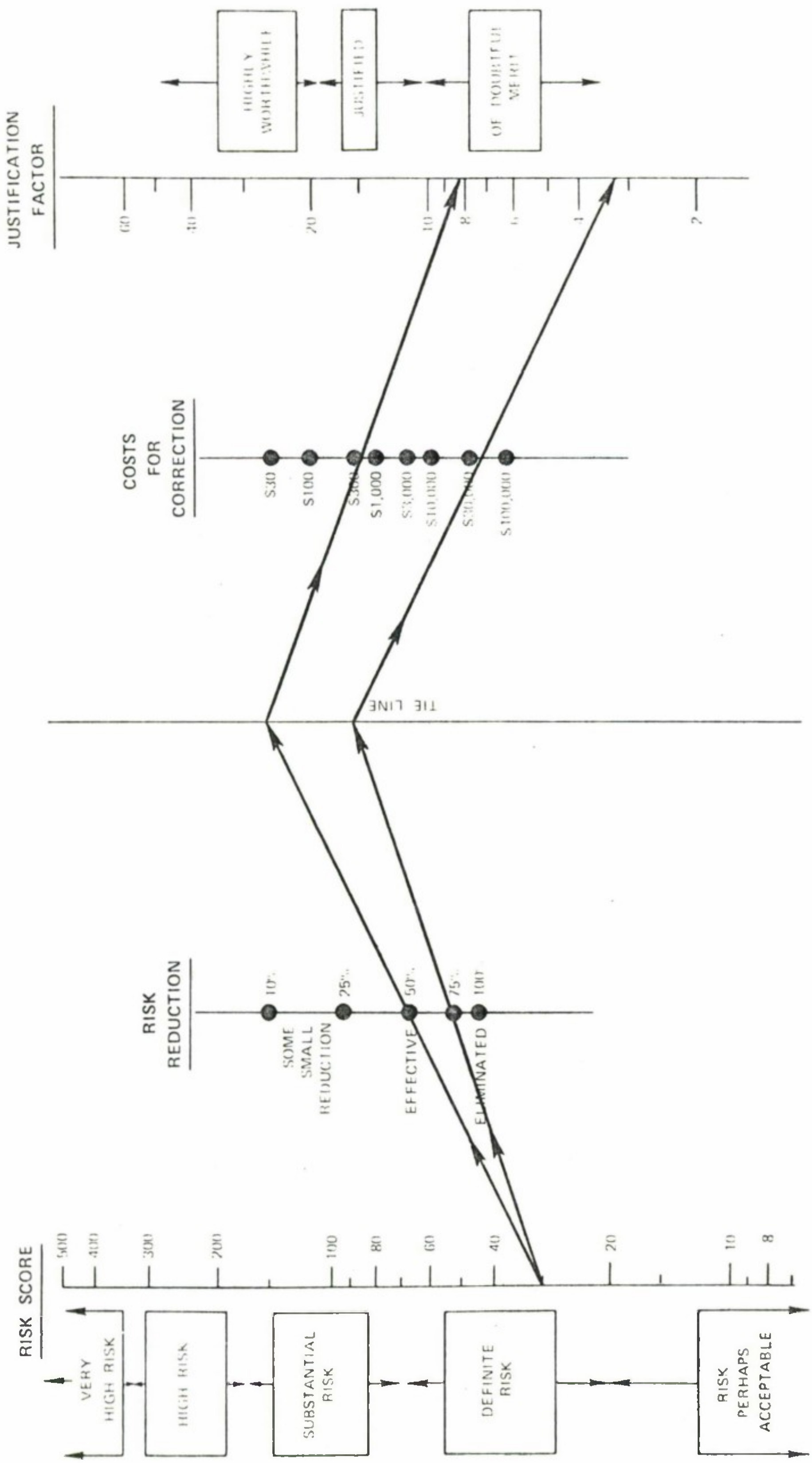

FIGURE 2. Cost Effectiveness Factors.

3. As for possible consequences, serious personal injuries would not be expected. For material damage of about $250,000, a consequence factor is assigned (by interpolation) a value of.................... 25

4. Risk score: 0.5 x 3 x 25 = (rounded)....................... 30

This risk score of about 30 lies within the range of possible risk, and some attention is indicated.

Graphical Solution. The above calculation can readily be performed graphically using Figure 1. First of the entry points are for designated likelihood and exposure. A line through these is extended to the tie line and then drawn through the point for possible consequences onto the line for risk score. The risk score indicated here lies at about 30 and is described as a possible risk, and some attention is indicated. This agrees with the algebraic results.

Justification Factor Calculation

It is suggested that the tank of the above risk score calculation be moved to a more remote location, one about 100 feet (30 meters) from the access road. This move would eliminate perhaps as much as 75% of the risk associated with the postulated accident. It is estimated that the move with its necessary replumbing would cost about $30,000. What is the justification factor and the cost effectiveness for this proposed safety action?

Algebraic Solution.

1. Risk score as computed above........................ 30
2. Value for 75% risk reduction.........................0.75
3. Divisor for costs, cube root of (30,000/100).........6.7
4. Justification factor and cost effectiveness
   30 x 0.75 ÷ 6.7 ....3.3

A cost effectiveness of only 3.3 indicates that the suggestion is of doubtful merit. But since the risk score of 30 indicates that some possible risk is present, it appears that alternative methods for risk control should be investigated.

It is suggested that a sturdy guard rail properly placed along the road could reduce the risk of damage here considerably, perhaps as much as 50%. Such a guard rail should cost only about $400. What is the justification factor and the cost effectiveness for this proposed safety action?

Algebraic Solution.

1. Risk factor as computed above...................... 30
2. Value for 50% risk reduction....................... 0.5

3. Divisor for costs, cube root of (400/100).......... 1.6
4. Justification factor and cost effectiveness:
   30 x 0.5 ÷ 1.6.................................. 9.3

A cost effectiveness of 9.3 indicates that the action suggested in this proposal is justified, but not overwhelmingly so. Nonetheless, it is to be preferred over the somewhat more effective but far more expensive action of moving the tank. But in view of such a moderate justification, perhaps alternative proposals should also be investigated. For example, would a well-enforced speed limit be a preferred action? Or should action with regard to this specific risk be deferred in favor of a more justified action for some other risk situation?

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1 Iowa Army Ammunition Plant
1 Picatinny Arsenal
1 Plastics Technical Evaluation Center, Picatinny Arsenal (SMUPA-VP3)
1 Radford Army Ammunition Plant
1 Redstone Arsenal
1 Rock Island Arsenal
1 White Sands Missile Range
1 Yuma Proving Grounds
3 Headquarters, U. S. Air Force
AFOP-00 (1)
FRDRD-AC (1)
1 Aerospace Defense Command, Ent Air Force Base
1 Air Force Systems Command, Andrews Air Force Base
1 Tactical Air Command, Langley Air Force Base (TPL-RQD-M)
1 Aeronautical Systems Division, Wright-Patterson Air Force Base
4 Air Force Flight Test Center, Edwards Air Force Base (H. Smith)
1 Air Force Missile Test Center, Patrick Air Force Base
1 Armament Development and Test Center, Eglin Air Force Base
1 Deputy Director of Defense Research and Engineering
1 Defense Advanced Research Projects Agency, Arlington
1 Armed Forces Staff College, Norfolk
12 Defense Documentation Center
3 Explosives Safety Board
1 Atomic Energy Commission (Technical Library)
1 Bureau of Mines, Pittsburgh
1 Department of Labor (Jerry Scannell)
1 Department of Labor, San Francisco (Larry Gromachey)
1 Federal Aviation Administration, Department of Transportation, Atlantic City (Chief, Airborne Instrumentation Unit)
1 Langley Research Center
1 Weapons System Evaluation Group
1 AC Electronics Division, General Motors Corporation, Milwaukee (Technical Library)
1 AMC Safety School, Louisville, Ky.
1 Aerojet-General Corporation, Azusa, Calif.
1 Aerojet Liquid Rocket Company, Sacramento, Calif. via AFPRO
1 Allegany Ballistics Laboratory, Cumberland, Md.
1 Applied Physics Laboratory, JHU, Laurel, Md.
1 Atlantic Research Corporation, Alexandria, Va. (Technical Library)
1 Autonetics, A Division of North American Rockwell Corporation, Anaheim, Calif. (Technical Library)
1 Battelle Memorial Institute, Columbus, Ohio (Technical Library)
1 Bell Aerosystems Company, Buffalo, N. Y. (Technical Library)
1 Bell Telephone Laboratories, Inc., Whippany Laboratory, Whippany, N. J. (Technical Library)
1 Carboline Company, St. Louis, Mo.
1 Center for Naval Analyses, University of Rochester, Arlington, Va. (Director, Naval Long Range Studies)
3 Chemical Propulsion Information Agency, Applied Physics Laboratory, JHU, Silver Springs, Md.

1 Convair Division of General Dynamics, San Diego, Calif.
1 E. I. duPont de Nemours & Company, Inc., Savannah River Laboratory, Augusta, Ga.
1 E. I. duPont de Nemours & Company, Inc., Wilmington, Del.
1 Esso Research and Engineering Company, Linden, N. J. (Dr. J. A. Brown)
1 Franklin Institute, Philadelphia, Pa.
1 General Dynamics, Pomona Division, Pomona, Calif. (Engineering Librarian)
1 General Precision, Inc., Librascope Division, Glendale, Calif. (Engineering Library)
1 Grumman Aerospace Corporation, Bethpage, N. Y. (Library Director)
1 Honeywell Incorporated, Minneapolis, Minn.
1 Hughes Aircraft Company, Culver City, Calif.
1 IIT Research Institute, Chicago, Ill.
1 ITT International Electric Corporation, Nutley, N. J.
1 Jet Propulsion Laboratory, CIT, Pasadena, Calif.
1 Lincoln Laboratory, MIT, Lexington, Mass.
1 Ling-Temco-Vought, Inc., Vought Aeronautics Division, Dallas, Tex.
1 Litton Systems, Inc., Woodland Hills, Calif.
1 Lockheed Missiles and Space Company, Palo Alto, Calif.
1 Lockheed Missiles and Space Company, Sunnyvale, Calif.
1 Los Alamos Scientific Laboratory, Los Alamos, N. Mex.
1 Marquart Corporation, Van Nuys, Calif.
1 McDonnell Douglas Corporation, Long Beach, Calif.
1 McDonnell Douglas Corporation, St. Louis, Mo. (Engineering Laboratory)
1 Midway Research Institute, Kansas City (Technical Library)
1 Minnesota Mining and Manufacturing Company, St. Paul, Minn.
1 Naval Warfare Research Center, Stanford Research Institute Menlo Park, Calif.
2 New York University, University Heights, New York
  Dr. John Grimaldi (1)
  Document Control-CJM (1)
1 Norden Division, United Aircraft Corporation, Norwalk, Conn.
1 North American Rockwell Corporation, Downey, Calif.
1 Northrop Corporation, Norair Division, Hawthorne, Calif.
1 Oak Ridge National Laboratory, Metallurgical Division, Oak Ridge, Tenn.
1 Philco Ford Corporation, Communication Systems Division, Willow Grove, Pa.
1 Polytechnic Institute of Brooklyn, Farmingdale, N. Y. (Aerodynamics Laboratory)
1 Purdue University, Lafayette, Ind. (Department of Chemistry, E. T. McBee)
1 Research Analysis Corporation, McLean, Va.
1 Rocketdyne, Canoga Park, Calif.
1 Rocketdyne, McGregor, Tex. (Rocket Fuels Division)
1 Rohm & Haas Company, Redstone Arsenal Research Division, Redstone, Ala.
1 Ryan Aeronautical Company, San Diego, Calif.
1 Sandia Corporation, Albuquerque, N. Mex.
1 Southwest Research Institute, Houston, Tex. (Dr. H. C. McKee)
1 Stanford Research Institute, Poulter Laboratories, Menlo Park, Calif.

1 TRW Systems, Redondo Beach, Calif.
1 Texas Instruments, Inc., Dallas, Tex.
1 The Bendix Corporation, Electrodynamics, North Hollywood, Calif.
1 The Boeing Company, Seattle, Wash.
1 The Boeing Company, Airplane Division, Wichita Branch, Wichita, Kan.
1 The Bunker-Ramo Corporation, Westlake Village, Calif.
1 The Dow Chemical Company, Midland, Mich.
1 The Rand Corporation, Santa Monica, Calif.
1 Thiokol Chemical Corporation, Huntsville Division, Huntsville, Ala.
1 Thiokol Chemical Corporation, Wasatch Division, Brigham City, Utah
1 University of California, Institute of Engineering Research, Berkeley, Calif.
5 University of California Lawrence Radiation Laboratory, (Technical Information Division) Livermore
  - C. G. Craig (1)
  - J. Bell/M. Martin (2)
  - M. C. Larsen/W. L. Nevil (1)
  - Kenneth Street (1)
1 Walter G. Legge Company, New York, New York
1 Westinghouse Electric Corporation, Baltimore, Md. (Engineering Library)